California Global Warming Solutions Act of 2006

Cement Technical Team

Focused Meeting to Discuss Mandatory Greenhouse Gas Emissions Reporting Concepts

April 11, 2007
Sacramento, CA
Cal/EPA Headquarters

Cement Technical Team Meeting Overview

- Overview of March 13, 2007 Meeting
- Mandatory GHG Emissions Reporting: Cement Plants
- Cement GHG Emission Estimation Methods
- Current Inventory for Cement
- Cement GHG Emissions Verification
- Next Steps and Schedule

Overview of March 13, 2007 Meeting

Cement Technical Team Meeting: March 13, 2007

- AB 32 Statutory Requirements
- California Climate Action Registry: Cement Reporting Protocol
- Initial Concepts for Mandatory Reporting
- GHG Emission Estimation Methods
- Current Inventory
- Cement GHG Emissions Verification

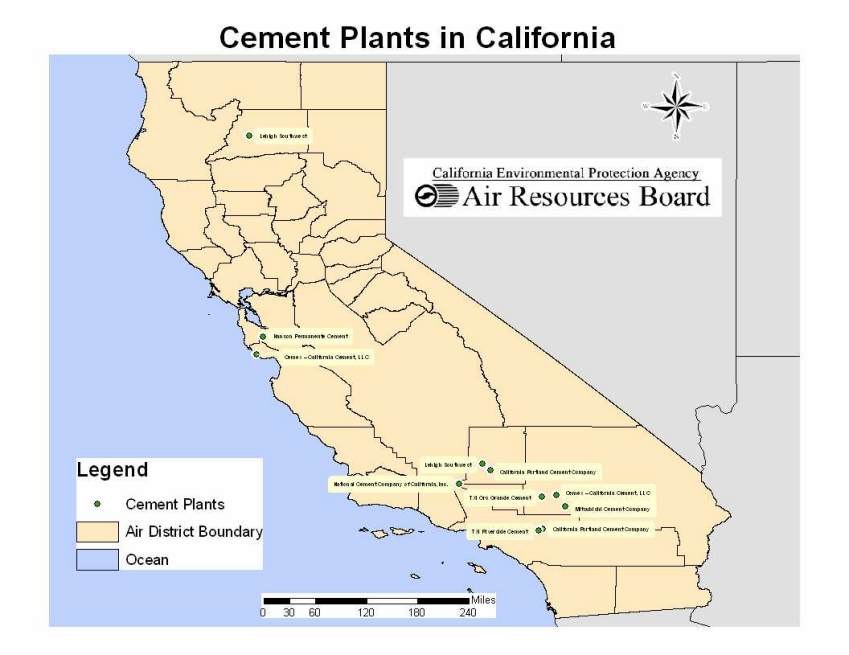
March 13, 2007 Meeting
Emission Sources to Report

- Options for Direct Process-Related Emissions
  - Clinker-Based Approach
  - Kiln-Input Methodology
- Direct GHG Emissions
  - Mobile Sources – Annual Fuel Consumption
  - Stationary Combustion – CEMS & Fuel Use
  - Fugitive Sources – HVAC & Refrigerants Not Relevant
- Indirect Emissions from Purchased Electricity Heat/Steam
- Efficiency Metric (Ton CO_2/Ton Cement)

Mandatory GHG Emissions Reporting: Cement Plants

Mandatory GHG Emissions Reporting: Cement Plants

- Cement Plants
- 11 Total
- Facility Level Reporting
- Direct Process-Related CO_2 Emissions
  - Default Values
  - Plant-Specific Data
- Direct GHG Emissions
- Indirect GHG Emissions
- Efficiency Metric (CO_2/ton cement)



Cement GHG Emission Estimation Methods: Direct Process-Related

Direct Process CO_2 Emissions

- Clinker-Based Methodology
  - California Climate Action Registry (Registry)
  - Intergovernmental Panel on Climate Change (IPCC) 2006 Guidelines
- Clinker Emission Factor
  - Activity Data
  - Default Calculation
  - Plant-Specific Calculation
  - Comparison Values
- CKD Data
- CO_2 Emissions Estimates
- Key Questions

Direct Process CO_2 Emissions

Clinker-Based Methodology: Registry/CSI

Process CO_2 emissions = [(Cli) (EF_{Cli}) + (CKD) (EF_{CKD})]

Where:

- **Cli = Quantity of clinker produced**
- **EF_{Cli} = Clinker emission factor**
- **CKD = Quantity CKD discarded**
- **EF_{CKD} = CKD emission factor**

Direct Process CO_2 Emissions

Clinker-Based Methodology: IPCC 2006 Guidelines

Process CO_2 emissions = $M_{Cl} \bullet EF_{Cli} \bullet CF_{CKD}$

Where:

- **M_{Cl} = Mass of clinker produced, tons**
- **EF_{Cli} = Clinker emission factor, tons CO_2/ton clinker**
- **CF_{CKD} = CKD correction factor, dimensionless**

Clinker Emission Factor: Activity Data

Clinker produced	Mass
CaO content of clinker	% Range= 60-67%
MgO content of clinker	% Range= 1-6%
Non-carbonate CaO	Mass
Non-carbonate MgO	Mass

EF_{Cli} = [(CaO content – non-carbonate CaO) • Molecular ratio of CO_2/CaO]
+ [(MgO content – non-carbonate MgO) • Molecular ratio of CO_2/MgO]

Clinker Emission Factor: Default Calculation

EF_{Cli} = [(CaO content – non-carbonate CaO) • Molecular ratio of CO2/CaO]
+ [(MgO content – non-carbonate MgO) • Molecular ratio of CO2/MgO]

Where:

CaO Content = 64.5%

Molecular Ratio of CO_2/CaO = 44g/56g = 0.785

MgO Content = 1%

Molecular Ratio of CO_2/MgO = 44g/40g = 1.092

EF_{Cli} = [0.645 • 0.785] + [0.01 • 1.092]

= [0.506325 tons CO_2 • 1,016 kg/ton] + [0.01092 tons CO_2 • 1,016 kg/ton]

= 514.45 kg + 11.10 kg = 525 kg CO_2/ton clinker

Clinker Emission Factor: Plant-Specific Calculation

EFCli = [(CaO content – non-carbonate CaO) • Molecular ratio of CO2/CaO] + [(MgO content – non-carbonate MgO) • Molecular ratio of CO2/MgO]

Where:

CaO Content = 65%

Molecular Ratio of CO_2/CaO = 44g/56g = 0.785

MgO Content = 1%

Molecular Ratio of CO_2/MgO = 44g/40g = 1.092

EF_{Cli} = [0.65 • 0.785] + [0.01 • 1.092] =
= [0.51025 tons CO_2 • 1,016 kg/ton] + [0.01092 tons CO_2 • 1,016 kg/ton]
= 518.44 kg + 11.10 kg = 530 kg CO_2/ton clinker

Clinker Emission Factor: Comparison Values

Cement Protocol	IPCC 2006	Registry/CSI	Plant-Specific
Default Clinker Emission Factor (EF_{Cli})	0.5101 ton CO_2/ton clinker =518 kg CO_2/ton clinker	0.5167 ton CO_2/ton clinker =525 kg CO_2/ton clinker	0.52117 ton CO_2/ton clinker = 530 kg CO_2/ton clinker
Mineral Content in Clinker	CaO = 65%	CaO = 64.5% MgO = 1%	CaO = 65% MgO = 1%

Direct Process CO_2 Emissions: Clinker-Based Methodology

California Climate Action Registry/CSI Equation

Process CO_2 emissions = [(Cli) (EF_{Cli}) + (CKD) (EF_{CKD})]

Where:

- **Cli = Quantity of clinker produced**
- **EF_{Cli} = Clinker emission factor**
- **CKD = Quantity CKD discarded**
- **EF_{CKD} = CKD emission factor**

Direct Process CO_2 Emissions: Clinker-Based Methodology

IPCC 2006 Guidelines Equation

Process CO_2 emissions = $M_{Cl} \bullet EF_{Cli} \bullet CF_{CKD}$

Where:

M_{Cl} = Mass of clinker produced, tons

EF_{Cli} = Clinker emission factor, tons CO_2/ton clinker

CF_{CKD} = CKD correction factor, dimensionless

Clinker-Based Methodology: CKD Data

Protocol	Registry/CSI	IPCC 2006
Equation Inputs	1. CKD Discarded 2. CKD Emission Factor	1. CKD Correction Factor
Equations	$EF_{CKD} = \frac{\frac{EF_{Cli}}{1+EF_{Cli}} \times d}{1-\frac{EF_{Cli}}{1+EF_{Cli}} \times d}$	$CF_{CKD} = 1 + (M_d / M_{cl}) \cdot C_d \cdot F_d \cdot (EF_c/EF_{cl})$
Where	EF_{Cli}=Clinker Emission Factor d = CKD calcination rate	M_d = CKD M_{Cl} = Mass of Clinker C_d = Fraction of carbonate in CKD F_d = Fraction of calcination EF_C = Carbonate emission factor EF_{Cl} = Emission factor for clinker

CO_2 Emissions Estimates: Registry/CSI & IPCC 2006

Assumptions	Default Values	Plant-Specific Data
100% CKD Recycled	620,048 ton CO_2	625,404 ton CO_2
2% Correction Factor	632,449 ton CO_2	637,912 ton CO_2

Where:

Clinker = 1.2 MMT/Year

Default EF_{Cli} = 525 kg CO_2/ton clinker

Plant-specific EF_{Cli} = 530 kg CO_2/ton clinker

CO_2 Emissions Estimates: Registry/CSI & IPCC 2006

Assumptions	Registry/CSI	IPCC 2006
Default Values	744,057 ton CO_2	669,652 ton CO_2
Plant-Specific Data	756,984 ton CO_2	675,436 ton CO_2

Where:

- Clinker = 1.2 MMT/Year
- CKD = 254,504 ton
- Default EF_{CKD} = 499 kg CO2/ton clinker
- Plant-specific EF_{CKD} = 529 kg CO2/ton clinker
- CF_{CKD} = 1.08 (Assumes 50% CKD Calcination Rate)

CO_2 Emissions Estimates: Registry/CSI & IPCC 2006

Assumptions	Registry/CSI	IPCC 2006
Default Values	744,057 ton CO_2	719,256 ton CO_2
Plant-Specific Data	756,984 ton CO_2	726,106 ton CO_2

Where:

- Clinker = 1.2 MMT/Year
- CKD = 254,504 ton
- Default EF_{CKD} = 499 kg CO2/ton clinker
- Plant-specific EF_{CKD} = 529 kg CO2/ton clinker
- CF_{CKD} = 1.16 (Assumes 100% Calcination Rate)

Direct Process Emissions: Organic Carbon in Raw Materials

CO_2 emissions from TOC in raw materials =

$$(TOC_{R.M.})\ (R.M.)\ (3.664)$$

Where:

$TOC_{R.M.}$	= Organic carbon content of raw material (%)
R.M.	= The amount of raw material consumed (t/yr)
3.664	= The CO_2 to C molar ratio

Direct Process Emissions: Organic Carbon in Raw Materials

CO_2 emissions from TOC in raw materials =

$$(TOC_{R.M.})\ (R.M.)\ (3.664)$$

Where:

- $TOC_{R.M.}$ = 0.2 % Default
- R.M. = Plant X consumes 1.9 MMT raw material per year
- 3.664 = The CO_2 to C molar ratio

CO_2 emissions from TOC in raw materials =
13,923 tons CO_2
(2% of CO_2 Emission Estimate)

Key Questions

- Clinker Emission Factor
  - Default Value
  - Plant-Specific
- Cement Kiln Dust (CKD)
  - CKD Discarded & Emission Factor
  - CKD Correction Factor
  - 2% CKD Correction
  - Percent Calcination CKD
- CO_2 Emissions Estimates
  - Registry/CSI
  - IPCC 2006

Additional Questions

- Do all cement plants have X-Ray Fluorescence (XRF)?
- Do any cement plants add non-carbonate raw materials to the raw meal?
- Quantify iron-oxide percent in the clinker?
- Cement kiln dust (CKD) collection process?

Cement GHG Emission Estimation Methods: Other Emission Sources

Stationary Emissions

- Non-mobile sources emitting GHGs from fuel consumption
  - Boilers, turbines, Internal combustion engines, flares, etc.
- Two methods:
  1. Measurement
     - Continuous Emission Monitoring System (CEMS) Reports
  2. Fuel Use calculation
     - Annual consumption

Stationary Emissions: Fuel Use Calculation

- Cement Kilns
- Non-Cement Kiln Units
- Quantity and Type of Fuel
  - Default Emission Factors
  - Plant-Specific Emission Factors
- Report Conventional and Alternative Fuels
- CO_2, CH_4, and N_2O

Stationary Emissions: Fuel Use Calculation

Total CO_2 Emissions (tons)	=	Total Annual Fuel Consumed (MM Btu)	•	Emission Factor (kg CO_2/ MM Btu)	•	0.001 (tons/kg)

Example:

3,600,000 MM Btu x 93.72 kg CO_2/MM Btu X 0.001 tons/kg

Total CO_2 Emissions = **337,392 tons CO_2**

Mobile Emissions

- On-Site
  - Off-Road Quarry Vehicles
  - Mobile Quarry Equipment
  - Trucks
  - Trains
  - Company Cars
  - Other Mobile Combustion Devices
- Annual Fuel Consumption
- Quantity and Type of Fuel

Mobile Emissions: Annual Fuel Consumption

Total Emissions (tons) = Total Annual Fuel Consumed (gallons) • Emission Factor (kg CO_2/gallon • 0.001 (tons/kg)

Example:

10,000 gallons x 8.78 kg CO_2/gallon x 0.001 tons/kg

Total CO_2 emissions = **87.8 tons CO_2**

Fugitive Emissions: Cement Production Process

- Methane Emissions from Fuel Storage
- Sample Calculation: Power/Utility Protocol
- 4-Step Process
  1. Identify the Total Tons of Coal Purchased.
  2. Identify the Appropriate Emission Factor Based on Coal Origin.
  3. Calculate Fugitive CH_4 emissions and Convert to metric tons.
  4. Convert CH_4 emissions to CO_2 equivalents and sum all subtotals.

Fugitive Emissions: Cement Production Process

$$\text{Total Fugitive } CH_4 \text{ Emissions} = \text{Fugitive Methane Emissions (scf)} \times \frac{0.04228 \text{ lbs } CH_4/\text{scf}}{2{,}204.6 \text{ lbs/ton}}$$

$$\text{Fugitive Methane Emissions} = 144{,}000 \text{ tons coal} \times 44.34 \text{ scf/}CH_4 \text{ ton} = 6{,}379{,}200 \text{ scf } CH_4$$

Example:

Total Fugitive CH_4 emissions = 6,379,200 scf CH_4 x 1.9178

Total Fugitive CH_4 emissions = 122.34 tons CH_4

Metric Tons CO_2e = Metric Tons GHG X GWP

Metric Tons CO_2e = 122.34 x 21 = **2,569 tons CO_2e**

Indirect Emissions: Electricity Use

1. Determine annual electricity usage purchased and consumed
2. Apply electricity emission factor
    1. CO_2 - eGRID subregion
    2. CH_4, N_2O – state specific
3. Calculate total annual emissions (metric tons)
4. Convert non-CO_2 gases to CO_2 equivalent
5. Total all CO_2 and non-CO_2 gases

Example:

50,000 kWh x 0.805 lbs CO_2/kWh = 15.04 metric tons CO_2

Cement Manufacturing: Efficiency Metric

CO_2 Emissions per ton of cementious product =

$$\frac{\text{Direct + Indirect } CO_2 \text{ emissions from cement manufacturing}}{\text{Own clinker consumed or added to stock} + \text{own clinker sold directly} + \text{gypsum, limestone, CKD \& clinker substitutes consumed for blending} + \text{cement substitutes}}$$

Example: $\frac{675{,}436 + 13{,}923 + 337{,}392 + 87.9 + 2{,}569 + 15.04}{1{,}200{,}000}$

CO_2 Emissions per ton of cement = 0.85 ton CO_2/ton cement

Key Questions

- Facility Data
  - Age of facilities?
  - Current controls?
- Estimation Methodologies
  - Multiple options or one approach?
- Efficiency Metric

Statewide GHG Inventory for Cement Production

Current Statewide GHG Inventory for Cement

- Compiled by California Energy Commission
- Covers 1990-2004 time series
- Primarily top-down
  - Based on state-level data
  - Process emissions estimates separate from combustion estimates
  - Combustion emissions fuel-specific
- Not based on reported data from individual facilities
- Approximately 2% of total, statewide GHG emissions (2004)

2020 Emissions Limit

- Based on total, statewide emissions
  - *Aggregated* from all sectors
  - Equivalent to 1990 statewide level
- 2020 forecast based primarily on energy projections
  - Current 1990-2020 difference: 174 MMTCO_2e*
  - Gap between 1990 and 2020 may change

**Source: March 2006 CAT Report*

Methodology for Estimating Statewide Cement Process Emissions

Process CO_2 emissions = Cli x (CaO x MWR) x CKD

Where:

Cli = State clinker production data (thousand metric tons)

CaO = Lime percent content of the clinker (.65) *

MWR = Molecular Weight Ratio of CO2 to CaO (.785) **

CKD = Cement kiln dust correction factor (1.02) ***

* Percent Lime factor (IPCC 2000 - *Good Practices Guidance*)

** 44g (CO2) / 56g (CaO) – Molecular Weight Ratio

*** CKD correction factor (IPCC 2000 - *Good Practices Guidance*)

Note: This is the same equation used in the current GHG inventory with updated activity data from USGS

Current Process Emissions Estimates for Cement Production

- Consists of direct emissions from calcination
- Example Calculation:

  2004 Process CO_2 Emissions from calcination:

(12,455) X (.65) X (44/56) X (1.02) /1000 = 6.49 MMTCO$_2$ Eq.

Process CO_2 Emissions from Cement (MMTCO$_2$ Eq.)

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
4.62	4.26	3.80	4.43	5.07	4.96	5.27	5.45	5.42	5.61	5.93	5.56	6.11	6.32	6.49

Source: California Energy Commission; Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004

Methodology for Estimating Stationary Combustion Emissions

Fuel Combustion CO_2 emissions =

(Fuel Use) x

(Fuel Heat/Fuel Use Unit) x

(% Oxidation) x

(Emission Factor)--*$MTCO_2$/Fuel Heat Unit*

Where:

Fuel Use = fuel use data from the CEC Energy Balance Report

Fuel Heat = fuel heat values from the CEC Energy Balance Report

% Oxidation = based on IPCC

EF: $MTCO_2$/Fuel Heat Unit = emission factors from the IPCC

Current Combustion Estimates for Cement

- **Combustion estimates for cement include natural gas, petroleum coke, and coal**

Natural Gas CO_2 Emissions from Cement ($MMTCO_2$ Eq.)

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
.18	.19	.17	.19	.13	.19	.19	.16	.23	.14	.16	.11	.17	.17	.18

Petroleum Coke CO_2 Emissions from Cement ($MMTCO_2$ Eq.)

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
0	.05	.15	.55	.91	1.44	.60	.75	.65	.64	.79	.73	.86	.86	.86

Coal Combustion CO_2 Emissions from Cement ($MMTCO_2$ Eq.)

1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
?	2.45	2.08	1.88	2.21	2.17	2.65	2.34	2.22	2.96	2.87	2.72	2.84	?	?

Source: California Energy Commission; Inventory of California Greenhouse Gas Emissions and Sinks: 1990 to 2004

Note: Staff currently determining 1990, 2003, and 2004 coal combustion CO_2 emissions

Estimate of Total 2004 Emissions from Cement Production

- 2004 Cement Production Emissions:

  6.49 MMTCO$_2$ Eq. from calcination process

  0.18 MMTCO$_2$ Eq. from natural gas combustion

  0.86 MMTCO$_2$ Eq. from petroleum coke combustion

  Total 7.53 MMTCO$_2$ Eq. in 2004 *

- CO_2 emissions from stationary source combustion and process emissions in separate categories

* Does not include combustion CO_2 emissions from Coal

Draft 2005 Emissions Estimate

- Calcination emissions based on the current methodology with updated clinker production data from USGS
- Current 2005 Draft Estimate from Calcination:

  5.97 MMTCO_2 Eq.

- Staff is currently updating CO_2 emission estimates for stationary combustion from cement manufacture

Cement GHG Emissions Verification

Next Steps and Schedule

Next Steps and Schedule

- Final Technical Team Meeting
  - May 9, 2007
- Public Workshop
  - May 23, 2007
- Staff Report in October
- Board Hearing in December

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GHG Mandatory Reporting Website
http://www.arb.ca.gov/cc/ccei/ccei.htm

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